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Perceived Social Support Moderates Neural Reactivity to Emotionally-Valenced Stimuli During Pregnancy

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Abstract

Reactivity to emotional information, measurable at the level of neural activity using event-related potentials, is linked to symptoms of affective disorders. Behavioral evidence suggests that contextual factors, such as social support, can alter emotional reactivity such that affective responding is normalized when social support is high. This possibility remains largely untested at the neural level, specifically through approaches that can offer insight into the mechanistic processes contributing to individual differences in emotional reactivity. Yet, such knowledge could be useful for prevention and intervention efforts, particularly with groups at risk for increased emotional reactivity, such as pregnant mothers for whom emotional distress predicts both maternal and child outcomes. Expectant mothers took part in a longitudinal study that tested whether the LPP, a neural index of reactivity to emotional information, was moderated by maternal perceptions of social support. In the third trimester of pregnancy, lower perceived social support was associated with an absence of a traditional LPP effect, which differentiates valenced from neutral stimuli. Findings suggest that perceptions of social support may normalize emotional processing at the neural level and highlight the potential importance of social support modulation of emotional reactivity during times of known biological change.

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Keywords

LPP; social support; pregnancy; mothers

1. Introduction

Atypical emotional reactivity is linked with myriad negative physical and mental health outcomes. There is increasing evidence that, although the forms are similar, levels of emotional distress linked to atypical emotional reactivity may be heightened in mothers, particularly during pregnancy (Balaji et al., 2007; Evans et al., 2001). Dysregulated affect in pregnancy is linked to poorer concurrent and postpartum functioning for pregnant women (Heron et al., 2004; Hoffman & Hatch, 2000; O'Hara & McCabe, 2013), suggesting that the ability to modulate emotional distress and reactivity could have long-term consequences. Yet, the putative mechanisms of emotional reactivity during pregnancy, and the ways they might be modulated, remain understudied. One possible candidate for the modulation of emotional reactivity is the perceived presence of social support. In non-pregnant adults, enhancing levels of social support appear to buffer emotional distress (Eisenberger et al., 2007; O'Hara, 1985), at the levels of both self-reported distress and physiological reactivity (Eisenberger et al., 2007; Gunnar, 2017). However, the extent to which this type of buffering might be present during pregnancy remains untested, as do the mechanisms by which buffering may occur. Such insights will be critical for informing socially based interventions that can enhance emotional well-being in mothers and offspring.

Emotional reactivity can be indexed at the level of biological function by the Late Positive Potential (LPP), an event-related potential (ERP) believed to denote the processing of affective or motivationally-salient stimuli at the neural level (Cuthbert et al., 2000). The LPP is visible at central-parietal electrode sites beginning roughly 300 ms after the onset of a stimulus. LPP amplitudes are larger for emotionally-valenced relative to neutral stimuli (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; MacNamara, Kotov, & Hajcak, 2016; Schupp, Flaisch, Stockburger, & Junghöfer, 2006; Weinberg & Hajcak, 2011) and are believed to be generated by neural networks that include the prefrontal cortex, insula, and posterior cingulate cortex for negative stimuli and the prefrontal cortex, amygdala, and precuneus for positive stimuli (Liu et al., 2012). The LPP is typically sustained for as long as a stimulus is presented, up to 6000 ms (Cuthbert et al., 2000; Hajcak et al., 2009), with maximal amplitudes visible by 1000 ms post-stimulus (Cuthbert et al., 2000). The LPP can also be sustained for at least 1000 ms following picture offset (Hajcak & Olvet, 2008).

The LPP can be differentiated into temporally distinct components, which is useful for understanding its association with different aspects of emotion processing (Foti et al., 2009). LPP amplitudes immediately following the presentation of emotionally-valenced stimuli likely reflect processes of emotional reactivity while sustained LPP amplitudes have been interpreted as reflecting the effects (on reactivity) of volitional processes of regulation (Codispoti et al., 2007). This temporal ordering is consistent with theoretical and empirical work demonstrating antecedent-focused emotion regulation strategies as most likely to impact the initial appraisal of stimuli as affectively salient, including the differentiation of

emotional from neutral information (Gross, 2001, 2002; Thiruchselvam et al., 2011); when participants are given instructions for emotion regulation prior to picture viewing, alterations in LPP amplitudes are visible as early as 200 ms post-stimulus (Hajcak & Nieuwenhuis, 2006; Moser et al., 2009). In contrast, response-focused strategies, which do not necessarily limit the appraisal of stimuli as affectively charged (Sheppes & Gross, 2011) are associated with changes in neural processing that are visible much later post-stimulus (Goldin et al., 2008; Thiruchselvam et al., 2011). As such, the discrete temporal windows of the LPP can be leveraged to index individual differences in distinct aspects of emotion processing at the neural level.

The physiological systems believed to at least partially underlie changes to observed and self-reported emotional reactivity during pregnancy are also linked to the LPP. Cortisol is a universal end product of the hypothalamic pituitary adrenocortical (HPA) axis, but shows normative increases in diurnal levels and blunted reactivity during pregnancy, with both patterns appearing most robustly in the third trimester (Collins et al., 1993; Schulte et al., 1990). In adults, heightened cortisol levels are also associated with LPP amplitudes, with greater post-stressor cortisol associated with a decline in the differentiation of emotionally-valenced from neutral stimuli (Alomari et al., 2015). This lack of differentiation between neutral and emotionally-valenced stimuli at the level of LPP echoes the pattern of LPP observed when depressive symptoms are elevated (Kayser, Bruder, Tenke, Stewart, & Quitkin, 2000; MacNamara et al., 2016). Notably, depressive symptoms, at both the behavioral (Bylsma et al., 2008; Sadek & Bona, 2000) and physiological levels (Bylsma et al., 2008; Phillips, Drevets, Rauch, & Lane, 2003; Proudfit, Bress, Foti, Kujawa, & Klein, 2015; Weinberg, Perlman, Kotov, & Hajcak, 2016),¹ are also some of the most prevalent affective disturbances in pregnant women. Thus, pregnancy may offer a unique opportunity to spotlight the biological systems that underlie changes in emotional reactivity that may serve as risk factors for subsequent disorder.

It is important to note that the degree to which changes in emotional reactivity, as denoted by LPP, reflect changes to emotional reactivity versus sustained processing – or both – is unclear, as prior work has not always distinguished early from late LPP windows. Namely, the traditional LPP effect has largely been examined from 300–1000 ms post-stimulus. Less work has focused on LPP amplitudes in a later time frame (i.e., 1000⁺ ms post-stimulus). This question has gone particularly unaddressed in pregnant women despite evidence for alterations to emotional reactivity during pregnancy using other ERPs. For example, the N170, a purported marker of the processing of facial emotion, appears to be amplified during pregnancy in response to angry faces (Raz, 2014). The absence of investigations that include multiple time windows for the LPP fails to leverage the temporal precision of the ERP technique and leaves a gap in our knowledge about critical processes of emotion during periods of potentially enhanced emotional reactivity.

¹There is some initial evidence that emotional reactivity may remain intact or even augmented in association with depression, though these effects have largely been observed during adolescence (Auerbach, Stanton, Proudfit, & Pizzagalli, 2015; Burkhouse, Owens, Feurer, Sosoo, Kudanova, & Gibb, 2017; Speed, Nelson, Auerbach, Klein, & Hajcak, 2016). Given our focus on emotion process during pregnancy, this work is noted but is not fully reviewed here.

There is both theoretical and empirical support for the possibility that the atypical patterns of biological function that may underlie symptoms of emotional distress can be altered, sometimes via simple structural changes in the environment (Beck, 2002). In non-pregnant adults, for example, enhancing actual or perceived levels of social support offers protection against the manifestation or augmentation of emotional distress (Eisenberger et al., 2007; O'Hara, 1985), an effect that likely operates via physiological function (Gunnar, 2017). Social support can generally be evaluated in two domains (Balaji et al., 2007). *Structural* aspects of social support include the number of individuals in a social support network and the homogeneity of network characteristics. In contrast, *functional* aspects of social support include the provision of resources and perceptions of interpersonal connectedness and shared values. Both structural and functional aspects of social support rely, at least in part, on an individual's perception that social support is available when needed (Heitzmann, 1988; Sarason et al., 1983). Although subjective, perceptions of social support are necessary factors for consideration given that an individual is unlikely to engage with even objectively high-quality social support networks if s/he is unaware that they exist or dubious that they would be useful.

Higher levels of social support are associated with normalized (i.e., less atypical) MRI-based patterns of emotional responses in areas of the brain to which the LPP has been localized (Eisenberger et al., 2007). Perceptions of adequate social support also appear to buffer HPA function, mitigating links between cortisol levels and psychological distress (Giesbrecht et al., 2013). Testing this possibility using the LPP would add to a growing literature on biological mechanisms of emotion that can be impacted by social interventions. In addition, conducting an investigation that leverages the temporal precision of the ERP technique can offer additional insight into whether social support primarily affects processes of emotional reactivity or subsequent emotion processing. That is, if early LPP amplitudes are normalized when social support is high, effects would suggest social support as a buffer against atypical reactivity to emotional stimuli. If late LPP amplitudes are normalized when social support is high, results would offer at least initial evidence that social support supports aids the regulation and ongoing evaluation of emotional stimuli.

A socially based mitigation of atypical emotion processing in pregnant mothers is also conceptually supported by the extant literature. For mothers specifically, social support is positively associated with physiological and psychological health and well-being (Balaji et al., 2007; Biaggi et al., 2016; Lancaster et al., 2010; Leahy-Warren et al., 2012) and negatively associated with postpartum depression (Leahy-Warren et al., 2012; Xie et al., 2009). Previous work also suggests that negative postpartum outcomes are exacerbated when mothers perceive available social support to be inadequate (Nylon et al., 2013) and may be mitigated by perceptions of greater social support (Collins et al., 1993). Although more women report symptoms of emotional distress in the prenatal than in the postpartum period (Evans et al., 2001), the possible impact of social support on pregnant women has not been tested.

Levels of social support are relatively stable across pregnancy (Chou et al., 2008; Hetherington et al., 2020; Norbeck & Anderson, 1989) despite reported levels of maternal emotional distress undergoing significant change. Retrospectively, women report more

prevalent physical than emotional symptoms during the first trimester (Rofé et al., 1993). This is consistent with the suggestion that emotional reactivity increases over time (Brooker et al., 2020; Pearson et al., 2009; Rofé et al., 1993) in pregnant women and echoes established patterns of change in cortisol (Collins et al., 1993; Schulte et al., 1990). Yet, patterns of change appear to shift from specific to global over time. At least one study has found greater emotional reactivity to negative stimuli in early pregnancy and enhanced reactivity more broadly (i.e., not only to negative stimuli) as pregnancy progresses (Glynn et al., 2004). Similarly, global responsiveness to negative emotional faces appears to be most pronounced during the second trimester of pregnancy (Roos et al., 2011). During the third trimester, women report more symptoms of emotional distress (Rofé et al., 1993) and encode threatening and general emotional faces with more accuracy compared to early pregnancy (Pearson et al., 2009). This supports the possibility that women demonstrate an enhanced emotional response initially to fearful stimuli that broadens to increased reactivity to a range of emotional stimuli during the third trimester. Such work again highlights the possibility that pregnancy, and most clearly the third trimester, offers a unique opportunity for investigating the effects of social support on neural reactivity to emotional stimuli that may be particularly relevant to emotional distress.

In sum, the current work aimed to address gaps in our knowledge by testing the degree to which social support moderated LPP amplitudes in pregnant women. We chose to test this question during pregnancy given that it offers a unique opportunity for highlighting variability in physiological systems that are linked to emotional reactivity. We followed women longitudinally from the second to third trimesters and tested whether perceptions of social support moderated differences in LPP amplitudes for emotionally-valenced compared to neutral stimuli. We hypothesized that high levels of social support would moderate differences in LPP amplitudes to emotional and non-emotional stimuli during pregnancy but that effects would be greatest during the third trimester, when increases in emotional reactivity appears to be greatest.

2. Method

2.1 Participants

Participants were enrolled in a longitudinal study of maternal emotion that included two prenatal laboratory visits, one each during the second ($M = 21.15$ weeks; $SD = 3.79$) and third trimester ($M = 35.92$ weeks; $SD = 1.47$) and one postnatal laboratory visit at infant age 4 months ($M = 4.27$, $SD = 0.62$). At the time of initial enrollment, maternal age ranged from 21 to 41 years ($M = 30.49$, $SD = 4.22$), with the majority of mothers in their thirties. Parity varied across the sample but was not evaluated for all mothers. Prior work indicates that parity is unrelated to maternal LPP amplitudes (Rutherford et al., 2018). Expectant mothers (henceforth “mothers”), were recruited through word-of-mouth (27%), informational brochures distributed via local doctors (26%), university email announcements (25%), flyers posted at local preschools and businesses (13%), referrals from local Women, Infants, and Children (WIC) offices (7%), and discussions at a local mothers’ club (2%).

Mothers were allowed to enroll in either their second or third trimester. Rolling recruitment procedures resulted in 81 participants at the second trimester visit, and 85 mothers at the

third trimester visit (11 new participants, 1 mother who skipped this phase because the baby was born early, and 6 participants who dropped out of the study). Seventy-four mothers completed assessments at both the second and third trimesters (retention = 91%). Complete data used for analyses were available from 72 mothers during the second trimester and 78 mothers during the third trimester. Given the interest of this work in emotional reactivity and distress, we note that mothers were generally low in depressive symptoms (Table 1), though they reported roughly the full range of symptoms at both assessments on a standardized measure (Cox et al., 1996). Additional participant demographics are presented in Table 1.

2.2 Procedure

Mothers scheduled prenatal visits either over the phone with laboratory staff or via an online booking site. Two weeks prior to the laboratory visit, mothers were mailed a packet of questionnaires to complete and bring with them to the laboratory. Questionnaires included assessments of mental health symptoms, perceptions of social support, and general demographic information. Upon arrival at the laboratory, mothers completed an informed consent procedure followed by two computerized tasks while neural activity was recorded using EEG. The current report focuses on surveys and EEG data from a computerized passive viewing task; details of the second task (go/no-go) are available from the authors but are not discussed further in the current report.

2.3 Measures

Passive Viewing Task.—Mothers passively viewed 120 colored images (40 positive, 40 negative, and 40 neutral) from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008)². Mothers were instructed to focus their attention on the screen while all of the images were presented for 1000 ms each in the center of a 23" computer monitor using Presentation® software (Neurobehavioral Systems, Inc.; Berkeley, CA). A blank screen was presented between images for 1500 ms followed by the presentation of a fixation cross for 500–1000 ms. The order of images was randomized within block.

EEG Data Collection and Processing.—EEG was recorded at each laboratory visit using a BioSemi Active 2 system (Cortech Solutions, LLC; Wilmington, NC) during the passive viewing task (Hajcak & Nieuwenhuis, 2006). Mothers were fitted with a 32-channel Bio-Semi elastic head cap. Electroconductive gel was placed into plastic electrode holders embedded into the cap. Ag-AgCl-tipped active electrodes were then secured into electrode holders, arranged according to the 10–20 labeling system. Data were sampled at a rate of 2048 Hz and referenced to the Common Mode Sense (CMS) and Driven Right Leg (DRL) electrodes during recording. Horizontal and vertical eye-movements were recorded via passive electrodes placed at the outer canthi of the left and right eye, and supra and infra

²Positive images used were: 1601, 2000, 2070, 2080, 2091, 2092, 2165, 2311, 2340, 4660, 4645, 4617, 4150, 5470, 5621, 5626, 5628, 7325, 8021, 8032, 8080, 8200, 8210, 8280, 8320, 8330, 8370, 8400, 8465, 8490, 8540. Negative images used were: 1300, 1301, 2053, 2120, 2710, 2800, 2900, 3160, 3220, 3230, 3300, 3350, 3500, 3530, 6200, 6210, 6212, 6230, 6244, 6250, 6260, 6312, 6313, 6370, 6540, 6550, 6560, 6570, 6571, 6821, 9040, 9050, 9421, 9490, 9520, 9600, 9620, 9911, 9920, and 9921. Neutral images included: 2102, 2190, 2480, 2570, 2840, 2880, 5390, 5500, 5510, 5532, 5534, 5731, 5740, 5800, 5900, 7000, 7002, 7004, 7006, 7009, 7010, 7025, 7030, 7034, 7035, 7040, 7060, 7080, 7090, 7100, 7140, 7150, 7175, 7190, 7217, 7224, 7233, 7235, 7491, and 7650. Valence and arousal ratings are available in Lang, et al., 2008 and were statistically different for selected negative and neutral images.

orbital sites of the left eye, respectively. Passive electrodes were also placed on each mastoid for offline re-referencing.

EEG data were processed offline using Brain Vision Analyzer (Brain Products GmbH). Continuous EEG was re-referenced to the average of the left and right mastoids, high-pass filtered at 0.1 Hz, low-pass filtered at 30 Hz, and corrected for eye movements and blinks (Gratton et al., 1983). Data were segmented (−400 to 2000 ms), and baseline corrected for 400 ms prior to stimulus presentation. Artifacts were identified, using a semiautomatic procedure, when one of the following criteria were met: a voltage step of more than 75 μ V between data points, a difference of 150 μ V per within 200 ms, amplitudes below 0.5 μ V within a 50 ms period, and activity that exceeded +100 μ V or −100 μ V. Remaining segments were visually inspected for artifacts.

Averages were created for each picture type. LPP averages were not created if fewer than 8 trials were available (Moran et al., 2013). On average, there were roughly 30 usable trials for each picture type at the second trimester visit (Positive: $M = 31.62$, $SD = 9.36$; Negative: $M = 30.03$, $SD = 10.50$; Neutral: $M = 30.30$, $SD = 10.44$) and 28 usable trials for each picture type at the third trimester visit (Positive: $M = 30.90$, $SD = 10.22$; Negative: $M = 27.60$, $SD = 12.79$, Neutral: $M = 28.02$, $SD = 12.17$). Numbers of trials included in LPP averages were not significantly different across picture types ($F(2, 78) = 0.11$, $p = 0.895$, $\eta_p^2 = .003$) or trimesters ($F(1, 39) = 0.025$, $p = 0.875$, $\eta_p^2 = .001$).

Principal Components Analysis (PCA).—A temporospatial PCA was used to empirically identify temporally and spatially distinct components consistent with LPP in each phase (Dien, 2012). PCA is a data reduction method that identifies and parses out linear combinations of data across both temporal and spatial domains, which allows for the identification of overlapping electrocortical activity (Dien, 2010; Foti et al., 2009; Pegg et al., 2019). Because LPP typically presents as a sustained ERP (Cuthbert et al., 2000; Hajcak & Olvet, 2008) and slow-going components may be split into multiple factors during PCA, data in the present study were downsampled to 1024 Hz for the purpose of the PCA. This sampling rate is consistent with prior PCA ERP work with LPP (Kujawa et al., 2013; MacNamara et al., 2018; Pegg et al., 2019), and allows for the analysis to be conducted using fewer data points, minimizing the likelihood of identifying temporospatial components due to artifact without altering the pattern of data.

Temporospatial PCAs were conducted separately for each trimester using ERP PCA Toolkit, version 2.83 (Dien, 2010). A temporal PCA was conducted first (Dien, 2010). Participants' averaged data were specified as variables, and participants, trial types, and electrode sites specified as observations. A Promax rotation was utilized to rotate the simple structure in the temporal domain (Dien, 2010; Dien et al., 2007). In order to identify temporal components, we used a parallel analysis (Horn, 1965) to compare the scree of the present data against the scree of a completely random data set (Cattell, 1966); this yielded three temporal factors (TF) during the second trimester and 19 TF for the third trimester that accounted for a greater proportion of the variance than those generated by the random data set.

The retained TF then underwent a spatial PCA (Dien, 2010; Dien et al., 2007). Electrode sites were identified as variables while participants, trial types, and TF were identified as observations. Infomax rotation was used to rotate the factors to independence in the spatial domain (Dien, 2010). Similar to the temporal PCA, a parallel test via scree plot was used to identify spatial components; this yielded one spatial factor (SF) during the second trimester and three SF during the third trimester. PCA factors were converted to microvolt scaling (Dien, 2012).

Results from the temporospatial PCA in both phases indicated the presence of components consistent with LPP in early and late windows. Specifically, for the second trimester, a component consistent with LPP peaked at 383 ms at M2 and at 1998 ms at M2. For the third trimester, a component consistent with LPP peaked at 694 ms at F3 and at 1900 ms at Fp2. Time window averages were then extracted from BrainVision Analyzer for each participant before the PCA across time windows around the peaks based on visualization of the data (i.e., 300–1000 ms for early LPP and 1000–2000 ms for late LPP) for further analysis. Examining the scalp distributions of the components revealed that they were widely distributed across the scalp. This suggests that the LPP components in the present sample were spatially diffuse; therefore, consistent with prior work (Moser et al., 2009; Schupp et al., 2006), the LPP was extracted at Pz to examine neural reactivity to valanced stimuli.

ERP averaging.—Early LPP was quantified as the mean EEG amplitude at electrode Pz from 300 to 1000 ms post-stimulus (i.e., during picture presentation) and late LPP quantified as the mean EEG amplitude between 1000 and 2000 milliseconds post-stimulus (i.e., after picture presentation). LPP values that fell outside of 3SD of the within-trial-type mean were winsorized to assure that variables were normally distributed ($n = 9$); results were unchanged when these mothers were excluded from analyses. Consistent with previous work (Hinton, Brownlow, McMurray, & Cozens, 2004; Moran et al., 2013), the internal consistency of the LPP was moderate to high (Phase 1: $\alpha = 0.67$, Phase 2: $\alpha = 0.78$).

Perceived social support.—At each of the prenatal visits, mothers reported their satisfaction with current levels of social support via the Social Support Questionnaire (SSQ; Sarason, Levine, Basham, & Sarason, 1983), a 27-item self-rating scale. Each item requested a two-part response: (1) listing the people to whom mothers felt they could count on for help or support should they experience a specific challenge and (2) indicating, on a six-point Likert scale (1 = very dissatisfied; 6 = very satisfied), their level of satisfaction with the overall level of support that would be available to them (Sarason et al., 1983).

In the current study, we focused on the SSQ Satisfaction Scale scores, which indicated the degree to which mothers were satisfied with their current levels of social support. We focused on SSQ satisfaction given that quantitative evaluations of social support (e.g., listing the individuals within a social network) may be less useful than qualitative evaluations of relationships and the satisfaction of social support when interpreting the effectiveness of social support (Sarason, Shearin, Pierce, & Sarason, 1987). Specifically, we believed that maternal perceptions would more accurately reflect the maternal experience than would quantitative lists. SSQ Satisfaction scores were calculated as a mean composite of the satisfaction ratings for the 27 items. The internal consistency of the SSQ Satisfaction Scale

was good, with reported alpha coefficients of 0.96 for the second trimester and 0.97 for the third trimester.

Research supports the utility of the SSQ for evaluating an individual's current perception of social support, with further research required to evaluate predictive qualities (Sarason et al., 1983). Therefore, concurrent scores were used in the present analysis (i.e., second trimester scores were used only for analysis in the second trimester, and third trimester scores used for third trimester analysis). On average, mothers reported a full range of satisfaction scores at both trimesters (Table 2). A majority of women reported high satisfaction in both trimesters (Second trimester: $M = 5.22$, $SD = .87$, Third trimester: $M = 5.27$, $SD = .84$). Although maternal satisfaction with social support was marginally greater in the third relative to second trimester (paired $t(59) = -1.885$, $p = 0.064$), the size of this effect was near zero ($d = 0.06$). Given this, and high stability in mothers' reports of social support across trimesters ($r = .538$, $p < .001$), ratings of perceived social support were mean composited for use in the repeated measures analysis, although given our hypothesis about second vs. third trimester effects, follow up tests used concurrent social support ratings to circumvent the possibility that effects for a given trimester might be driven by social support ratings from another semester. Note, however, that this is for ease of interpretation; the pattern of results is unchanged if mean or concurrent scores are used.

2.4 Missing data

LPPs were available from 80 mothers at the second trimester visit. One mother did not complete the LPP task due to equipment malfunction. LPPs were available from 79 mothers at the third trimester visit, with missing data resulting from experimenter error ($n = 4$) or equipment malfunction ($n = 2$). Social support questionnaires were available from 72 mothers during the second trimester and 78 mothers during the third trimester. Missing questionnaire data resulted from participants not returning the questionnaire packets or skipping questionnaire items. Overall, complete data were available from 72 mothers during the second trimester and 78 mothers during the third trimester. An examination of patterns of missing data suggested that data were missing at random, with patterns of missingness largely reflecting the tendency to be missing multiple ERP measures. A complete-case analysis strategy was adopted, resulting in a final analytic sample of 63 mothers for repeated measures analysis.

2.5 Plan for Analysis

We used a Repeated Measures Analyses of Variance to first establish whether social support moderated differences in LPP amplitudes for valenced (positive or negative) relative to neutral trials in the early and late time windows across trimesters. A significant overall interaction was probed by testing differences in LPP amplitudes for valenced (positive or negative) relative to neutral trials in the early and late time windows. Significant interactions at this level were probed by examining the LPP effects separately for the second trimester and third trimesters at high and low levels of social support.

Results

Preliminary analyses.

Means and standard deviations for variables are reported in Table 2. LPP amplitudes (within trial type and window; all F s < 1.367) did not statistically differ across assessment. Bivariate correlations between maternal LPP amplitudes and perceptions of social support were nonsignificant (all $|r$ s < 0.21).

Repeated measures analysis.

A 2 (trimester: second vs. third) by 2 (window: early vs. late) by 3 (valence: positive vs. negative vs. neutral) Repeated Measures ANOVA that included mean maternal social support returned a significant four-way interaction ($F(2,122) = 4.140$, $p = 0.020$, $\eta_p^2 = 0.064$). We probed this interaction by testing the effect of social support on LPP at each trimester.

Second trimester.

A 2 (window: early vs. late) by 3 (valence: positive vs. negative vs. neutral) Repeated Measures ANOVA revealed a significant 2-way interaction ($F(2,156) = 9.069$, $p < 0.001$, $\eta_p^2 = 0.104$) between valence and time window. Follow-up paired samples t -tests suggested that, as shown by Figure 1, LPP to negative trials was greater than LPP to neutral trials in both the early and late windows, though the effect size was larger in the early ($t(78) = 6.616$, $p = 0.000$, $d = 0.871$) relative to the late window ($t(78) = 3.095$, $p = 0.003$, $d = 0.476$). Similarly, LPP amplitudes to positive trials was greater than LPP to neutral trials in both the early ($t(78) = 5.243$, $p = 0.000$, $d = 0.557$) and late ($t(78) = 2.664$, $p = 0.009$, $d = 0.313$) windows, again with a larger effect size in the early time window. Negative trial amplitudes were greater than positive trial amplitudes, but only in the early window ($d = -0.310$; late: $t(78) = -1.334$, $p = 0.186$).

Most importantly for the aims of the current study, maternal satisfaction with social support did not moderate valence effects ($F(2,132) = 0.034$, $p = 0.967$, $\eta_p^2 = 0.001$) or the window by valence interaction ($F(2,132) = 1.445$, $p = 0.239$, $\eta_p^2 = 0.021$), suggesting that maternal perceptions of social support were unrelated to differences in neural reactivity to emotionally-valenced and neutral stimuli in both the early and late windows.

Third trimester.

In the third trimester, a 2 (window: early vs. late) by 3 (valence: positive vs. negative vs. neutral) Repeated Measures ANOVA revealed a significant effect of valence ($F(2,150) = 13.921$, $p < 0.001$, $\eta_p^2 = 0.157$); a nonsignificant window by valence interaction suggested that responses to negative, positive, and neutral stimuli did not differ across early and late windows ($F(2,150) = 1.173$, $p = 0.312$, $\eta_p^2 = 0.015$). Consistent with this, a probe of the valence effect showed that LPP amplitudes to negative trials were greater than LPP amplitudes to neutral trials in both the early ($t(78) = 3.851$, $p = 0.000$, $d = 0.601$) and late windows ($t(78) = 4.080$, $p = 0.000$, $d = 0.501$). LPP amplitudes to positive trials was similarly greater than LPP to neutral trials in both the early ($t(75) = 3.817$, $p = 0.000$, $d = 0.486$) and late ($t(75) = 2.639$, $p = 0.010$, $d = 0.162$) windows. Positive and negative LPP

amplitudes did not differ in either the early ($t(76) = -1.628, p = .108$), or late ($t(76) = -1.796, p = .077$) windows.

Importantly, maternal levels of satisfaction with social support moderated differences in LPP amplitudes for valenced relative to neutral trials (valence X window X social support: $F(2,134) = 6.586, p = 0.002, \eta_p^2 = 0.090$). Probing social support at the traditional $\pm 1SD$ -centered values would have resulted in two re-centered values that each reflected a general satisfaction with levels of social support rather than comparing putatively satisfied and dissatisfied values. Thus, we re-centered social support at the values of 2 and 5, both of which were represented in the data, so that low levels would reflect levels of relative dissatisfaction with social support (“fairly dissatisfied”) and high levels would reflect relative satisfaction with social support (“fairly satisfied”). Re-centering at meaningful scale values remains in accordance with best-practice recommendations (Aiken & West, 1991; Hayes, 2018). This probe revealed a significant difference in LPP amplitudes to valenced relative to neutral trials when perceived levels of social support were high ($F(2,134) = 9.320, p < 0.001, \eta_p^2 = 0.122$), suggesting that pregnant women were showing the traditional LPP effect, with larger amplitudes to positive images ($M = 3.550, SE = 0.458; F(1, 67) = 5.742, p = 0.019$) and negative images ($M = 4.622, SE = 0.595; F(1, 69) = 15.595, p < 0.001$) than to neutral images ($M = 1.567, SE = 0.627$). The absence of a significant window by valence interaction ($F(2,134) = 1.337, p = 0.266, \eta_p^2 = 0.020$) suggested that this effect was not limited to only the early or late window.

In contrast, at low levels of social support, there was no significant effect of valence ($F(2, 134) = 2.220, p = 0.113, \eta_p^2 = 0.032$), but there was a significant window by valence interaction ($F(2,134) = 5.917, p = 0.003, \eta_p^2 = 0.081$). A probe of the two-way interaction suggested no effects of valence on LPP amplitudes during the early window ($F(2,134) = 0.674, p = 0.511, \eta_p^2 = 0.010$) but significant effects of valence on LPP amplitudes in the late window ($F(2,134) = 5.135, p = 0.007, \eta_p^2 = 0.071$). During the late window, LPP amplitudes to negative images were greater than LPP amplitudes to positive images ($F(1, 67) = 11.646, p = 0.001, \eta_p^2 = 0.148$). However, neither LPP amplitudes to positive images ($F(1, 67) = 1.322, p = 0.254, \eta_p^2 = 0.019$) nor LPP amplitudes to negative images ($F(1, 69) = 3.361, p = 0.071, \eta_p^2 = 0.046$) were greater than LPP amplitudes to neutral images. This suggests an absence of the traditional LPP effect (valenced > neutral) at low levels of social support.

3. Discussion

We found evidence that perceptions of social support during pregnancy moderated neural responses to emotional stimuli assessed using LPP. When participants reported less satisfaction with the social support available to them, there was a lack of discrimination between emotionally-valenced and neutral stimuli at the neural level. This effect was consistent across both early and late LPP windows but was specific to the third trimester of pregnancy.

During the third trimester of pregnancy, high levels of social support were associated with the traditional LPP response, with greater LPP amplitudes for emotionally-valenced relative

to neutral stimuli. Thus, at high levels of social support, patterns of maternal LPP were consistent with expectations for typical function. In contrast, when perceived levels of support were low, LPP amplitudes did not differ for valenced relative to neutral trials. The presence of LPP effects in both the early and late windows offers initial evidence that mothers' perceptions that they have the social support that they need, whether or not strong social networks objectively exist, can impact both early neural reactivity to emotional stimuli and subsequent emotional processing (Codispoti et al., 2007). This is of potential interest because it suggests that a benefit of enhancing social support for mothers, who might be at risk for high levels of emotional distress, is possible reductions in atypical neural reactivity to emotional stimuli (e.g., appraisal of a stimulus as emotionally valenced) and/or adaptive changes to ongoing emotional processing. The current study was not designed to tease apart mechanisms of emotional reactivity and subsequent regulation, but rather to leverage the temporal benefits of the ERP approach to begin to explore the possibility that one or both are important for enhancing adaptive emotional function.

Our pattern of findings is also consistent with previous work finding a normalization of psychophysiological reactivity (Eisenberger et al., 2007; Kamarck et al., 1990) and the enhanced regulation of emotional arousal (Coan et al., 2006; Gross, 2002) in the presence of social support. At least one study has similarly shown that, at the peak response of an acute stressor, there appears to be a lack of differentiation between neutral and emotional information (Alomari et al., 2015). Results from this work appear to be primarily driven by the interpretation of neutral information as emotionally valenced rather than a blunting of response to emotional stimuli. Other work has indeed suggested that social support during pregnancy can decrease biological sensitivities to emotional distress (Giesbrecht et al., 2013). To our knowledge, this is the first study to demonstrate the LPP as a putative mechanism for such an effect in pregnant women. All of the bivariate correlations between social support and LPP in our sample were nonsignificant, suggesting that our effect is not driven by primarily by one trial type. Thus, it will be important for subsequent investigations to use experimental manipulations to demonstrate whether social support might be more robustly associated with decreased reactivity of emotional information, a diminished tendency to interpret neutral stimuli as valenced, or both.

That the normalization of the LPP by social support was visible only during the third trimester of pregnancy is consistent with our theoretical grounding in the third trimester as a period of putatively maximal reactivity. Emotional distress is believed to peak between roughly 34 and 36 weeks of pregnancy (Figueiredo & Conde, 2011), an effect that has been demonstrated in other (non-EEG) work with this sample (Brooker et al., 2020). Similarly, increases in cortisol levels, which have demonstrated associations with LPP amplitudes, peak in the third trimester (Collins et al., 1993; Schulte et al., 1990). Peaks in both mean levels and variability in systems of emotional reactivity in the third trimester may make the effects of social support more visible during this period. That is, it may be the case that high levels of perceived social support minimize otherwise-typical increases in emotional distress during the third trimester. In this way, a sample of pregnant women can be used to observe individual differences in emotional reactivity and the viability of enhanced social support as a point of intervention.

Importantly, this pattern of findings also suggests that, although LPP amplitudes are relatively stable over time (Codispoti et al., 2006; Hajcak et al., 2010), individual differences in the association between environmental factors like social support and LPP amplitudes may vary across sensitive periods of development. This is consistent with the interpretation of the LPP as sensitive to the salience and emotional intensity of the emotion-eliciting experience (Hajcak et al., 2010). That is, to the degree that mothers may become more sensitive to environmental input during a sensitive period of development like pregnancy (Del Giudice et al., 2011), the impact of environmental factors on LPP amplitudes may become enhanced. Thus, the timing by which perceptions of social support impact emotional reactivity will be an important area for future study, as will work to demonstrate the generalizability of the current effects beyond pregnancy. Specifically, although the broader literature does not suggest that social support would offer benefits only to emotional reactivity in pregnant mothers, or that such an effect would operate through different mechanisms outside of pregnancy, this possibility cannot be directly tested in the current sample, which includes only low-risk pregnant women.

Finally, this work offers initial evidence for a possible point of intervention for mitigating the effects of emotional distress in pregnant mothers. Namely, atypical emotional processing during the third trimester was only present when social support was perceived to be low. Importantly, we focused on maternal *perceptions* of social support rather than objective measures of the size of the social support network. This means that our results imply that although social support may not change LPP amplitudes per se, an intervention that simply changes perceptions of social support may be enough to disrupt atypical processes of emotional reactivity and regulation at the neural level.

Limitations

The primary limitations of the current study center around power and generalizability. Despite consistency with previous work, findings should be replicated in a larger and more diverse samples. The limited sample size included in the current study suggests that estimates resulting from the four-way interaction are underpowered and should be interpreted with caution. A post-hoc analysis of achieved power suggests that power was roughly 0.68 for the four-way interaction. Although low power is typically most concerning regarding the possible presence of a false negative (Type II error), it also likely indicates some degree of instability in the effect size estimate. Similarly, the degree to which results might be generalized will be clarified by additional work. This area of research will also benefit from additional work in racially and ethnically diverse samples as well as samples that include non-pregnant women in order to clarify the generalizability of these effects. While we do not believe that social support would impact emotional reactivity via different mechanisms in pregnant and nonpregnant women, we cannot directly test this possibility in a sample of pregnant women.

In addition, the current study recruited from a community sample, and as such did not obtain history of depression or related mental illness. Further research would benefit from obtain mental health history in order to more fully characterize influences on the neural and behavioral correlates of emotion reactivity in pregnant mothers and to determine whether

similar mechanisms might be at play in a clinical sample. Similarly, as with all correlational work, experimental designs will be needed to more precisely pinpoint mechanistic associations between social support and maternal emotion processing.

Given previous research suggesting particularly strong increases in emotional distress in first time mothers, compared to other mothers (Leahy-Warren et al., 2012), a possible limitation of the present work is that the sample includes both first-time and non-first-time mothers. Importantly, the pattern of findings for first-time relative to non-first-time mothers suggests that social support may be *particularly* important for first-time mothers, supporting a hypothesis that the current effects would be larger, not eliminated, in a sample of only first-time mothers. Nonetheless, this will be an important avenue for future research.

Finally, the current study focused on perceived satisfaction with social support, given literature supporting the relative importance of satisfaction with social support relative to structural aspects of social support (e.g., the number of individuals in a network; network characteristics, etc.; Heitzmann, 1988.; Sarason et al., 1987; Sarason et al., 1983). To our knowledge, research linking objective ratings of quantity and quality of social support related to maternal perceptions of social support during pregnancy are limited. Although maternal perceptions of social support are important for the question at hand, additional work that delineates influential aspects of social support would help to frame the boundaries of the current effects. Therefore, further work that includes functional aspects of social support is warranted.

Conclusions

We found that social support modulated LPP amplitudes during emotion-elicitation during the third trimester of pregnancy. Lower perceived social support was associated with reduced differences in LPP amplitudes for valenced relative to neutral stimuli. Our findings suggest that enhancing perceptions of social support may offer protection from emotional distress and offering a putative mechanism for mitigating emotional reactivity in pregnant mothers.

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Figure 1.
LPP at Pz during the second trimester (left) and third trimester (right) assessments.

Table 1.

Participant demographics

Race/Ethnicity		
	White	89%
	Non- Hispanic	96%
	Asian	8%
	American Indian	1%
	African American	1%
	Mixed Race	1%
Gross Annual Family Income		
	<\$15,000	8%
	\$16,000 to \$50,000	28%
	\$51,000 to \$90,000	29%
	>\$91,000	23%
	Did not Respond	12%
Mother's Education Level		
	High School Graduate	4%
	Some College	20%
	College Degree	37%
	Post-Baccalaureate Education	39%
Maternal Depressive Symptoms		
	Second Trimester	$M = 6.30$ ($SD = 3.98$)
	Third Trimester	$M = 5.22$ ($SD = 4.24$)

Table 2.

Descriptive statistics for primary variables

	Second Trimester				Third Trimester			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Positive LPP								
Early	3.1598	5.1307	-10.8944	15.8752	3.4591	4.9838	-11.4728	16.3179
Late	3.9811	4.9634	-14.3972	15.5645	4.1463	4.7583	-11.2095	16.6587
Negative LPP								
Early	4.7010	5.6657	-17.4362	20.5409	4.5713	6.0029	-16.2078	20.3573
Late	4.7618	5.4245	-10.2433	17.5699	5.4099	6.2378	-10.7553	24.4851
Neutral LPP								
Early	0.5563	3.8535	-10.9593	13.6872	0.9478	6.0650	-18.6805	19.6195
Late	2.4417	4.3300	-11.3492	13.9786	2.3319	6.0456	-7.6409	20.8329
Perceived Social Support	5.2230	0.8678	1.1500	6.0000	5.3304	0.6818	0.8900	6.0000